A MULTIATTRIBUTE SUPPLIER SELECTION AND ORDER QUANTITY ALLOCATION MODEL WITH GREEN PROCUREMENT CONSIDERATIONS

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ABSTRACT

One of the key challenges of current procurement decisions is to consider more than just a single attribute such as cost. Consequently, multiattribute procurement has emerged as an important research direction. This paper proposes a model for selecting the vendors to employ and determining the order quantities to allocate to them while taking into considerations the criteria of cost, quality, delivery reliability, and carbon emission of the purchased items. The procurement decision consists of sourcing multiple products from multiple suppliers, for delivery to multiple facilities. Further, we consider a competitive and business-constrained sourcing environment in which the vendors offer discounts on total amount of sales volumes not on the quantity or variety of products purchased from them. The procurement problem is formulated as a multi-objective mixed integer model.

Keywords: Green procurement, Supplier selection, Multi-objective programming, Volume discount, Mixed integer linear program.

INTRODUCTION

Environmental sustainability of a supply chain depends to a large extent on the procurement strategy of its supply chain members, and supply chain managers are now under growing pressure for reducing the carbon emission of their supply chains.

Vendor selection plays an important role in the greening of the supply chain. A strong relationship between the selection of green suppliers and the implementation of a green supply chain strategy has been reported in the study of Seuring and Müller (2008). Many researchers have addressed supplier selection issue in the green supply chain from the perspectives of environmental sustainability (Bai and Sarkis, 2010, Enarsson, 1998, Handfield et al., 2002, Humphreys et al., 2003a, Humphreys et al., 2003b, Hsu and Hu, 2009, Lee et al., 2009, Noci, 1997, Rao, 2005 and Walton et al., 1998). However, very few studies have addressed the carbon emission and the related issues for supplier evaluation. Recently, Abdallah et al., (2012) proposed a novel approach wherein the company selects its suppliers based on the trade-off between supplier's emissions and their component costs and can decide based on a carbon trading mechanism, to either sell or buy carbon credits while monitoring its own emissions.

The selection of vendors (suppliers) and the determination of order quantities to be placed with those vendors are strategic purchasing decisions that commit significant resources and impact the firm's performance (Burton, 1988). Depending on the purchasing situation, selecting the right vendors from a large number of possible suppliers with various levels of capabilities and potentials is a difficult and time-consuming task that is often driven by multiple criteria. In his seminal work on vendor selection criteria, Dickson (1966) identified 23 different criteria by which purchasing managers have selected vendors in various procurement environments. In practice, item cost, product quality, delivery performance, and supply capacity have been found to be the most frequently used vendor evaluation criteria. A review of 74 supplier selection articles, by Weber et. al. (1991) found that these four criteria received the greatest amount of attention in the earlier literature.

Recently, due to the rising environmental protection awareness and in response to climate change, large organizations have begun to extend their carbon management strategies beyond their direct corporate boundaries and into their supply chains by actively seeking suppliers with products having the least environmental impact taking into account such factors as climate impact, chemical used, resource consumption, and carbon emission (CDP 2010). Therefore, supplier ability to minimize greenhouse gases and carbon emission is becoming one of the criteria for supplier selection. This paper deals with the problem of vendor selection and order quantity allocation where buyers order quantities from different vendors in a multiple sourcing competitive environment based on the conflicting criteria of price, delivery performance, quality, and carbon emission.

Identifying suppliers with the lowest item price in a given industry becomes a major challenge for purchasing managers especially when suppliers offer multiple products and volume-based discount pricing schedules. In this environment, the supplier induces the buyer into making large purchases by offering discounts on the total value of sales volume, not on the quantity or variety of products purchased over a given period of time. In traditional quantity discount pricing schedules, price breaks that are function of the order quantity existed for each product, regardless of the total magnitude of business the buyer contracts with the supplier over a given period of time.

Recently, because of the advent of just-in-time inventory replenishment, a strategy which calls for ordering smaller quantities more frequently as needed, vendors are finding it more meaningful to give discounts based on the total value of multiproduct orders placed by a given buyer. Table I illustrates a business volume discount schedule with three discount brackets. For example, purchases worth less than \$100,000 get no discount. However, when the total purchase value reaches \$100,000, but does not exceed \$1,000,000, the buyer gets an across the board 5% discount applicable to all purchases, not just those above the \$100,000 cutoff point. A similar explanation applies to the third discount bracket. For example, purchases worth \$1,000,000 are discounted 10% to \$900,000.

Table I. Volume Discount Schedule

Sales Volume (in thousand \$)	Percent Discount
0 to under 100	0
100 to under 1,000	5
1,000 and over	10

Material and product quality is another critical factor of the vendor selection decision. Many firms are now willing to purchase entire subassemblies or even finished products from suppliers. Accordingly, the larger the proportion of the final product that gets outsourced the greater the impact suppliers have on overall product quality and cost. It is not uncommon, nowadays, for major buyers to test products before purchase to rate a potential supplier's quality level and determine if this level is commensurate with their organization's quality expectations. Quality is generally measured by the percentage of purchased items that gets rejected by the buying organization for not meeting its quality standards. A number of experimental studies conducted by Verma and Pullman (1998) reveal that managers perceive quality to be the most important attribute in the vendor selection process. Yet, the same sample of surveyed managers was found to assign higher weight to cost and delivery performance than quality when choosing a supplier, thus reflecting the fuzzy nature of the decision making process.

Central in many procurement situations, especially those supporting just-in-time manufacturing operations is the timely delivery of purchased items. Poor delivery performance disrupts production schedules and results in lost sales. As a result, many organizations closely monitor their suppliers' on-time delivery performance as measured by the percentage of units missing their scheduled delivery time windows at some given location.

Another criterion, arising from the need of sustainability is green procurement. A growing number of environmentally-conscious consumers are exerting pressure on firms to find new and innovative ways of optimizing their supply chain across all its stages to reduce carbon emissions and to seek implementation of green procurement practices that minimize their carbon footprints. The result is a procurement environment in which all suppliers and manufacturers are competing to reduce carbon emissions, in order to increase their market share. In this paper we assume that carbon emission come from two main sources: (i) the carbon embedded in the raw material supplied; and (ii) the supplier's facilities (e.g. plants) where the emissions level is proportional to the size of these facilities. One way of accounting for greenhouse gas emissions (GHGE) is to measure the embedded emissions (also referred to as "embodied emissions") of produced goods in grams or pounds of carbon dioxide (CO_2) per unit (Voorspools et al., 2000).

Vendor selection is a multicriterion decision that affects the number and types of vendors to employ, as well as the order quantities to place with these vendors. The joint consideration of procurement cost, product quality, delivery performance, carbon emission, and supply capacity criteria complicates the selection decision because competing vendors have different levels of achievement under these criteria. For example, the vendor with the least expensive price in a given industry may not have the best delivery performance, product quality, or carbon emission. Likewise, suppliers of greener products may not be able to provide volume-based discounts comparable to other competing suppliers or meet quality and delivery requirements of the buying organization. Vendor selection is therefore an inherently multiobjective decision that seeks to reduce procurement cost, maximize product quality, maximize delivery performance, and minimize carbon emissions concurrently. The presence of volume discounts further complicates the procurement problem since the buying decision is no longer based on a single product that can be purchased from one or more vendors, but on the collection of items that can be sourced from a single vendor.

This paper introduces a multi-objective mixed integer programming model to support vendor selection and order quantity allocation in a multiproduct multivendor competitive environment in which the suppliers offer discounts on the total amounts of sales volumes not on the quantity or variety of products purchased from them. The multi-objective model is formulated in such a way to simultaneously determine the optimal number of vendors to employ and the order quantities they must supply to each facility or plant in the system so as to concurrently minimize total purchase cost, maximize product quality, maximize on-time deliveries, and minimize carbon emission of the purchased items while satisfying capacity and demand requirement constraints.

MODEL DEVELOPMENT

Consider a procurement situation in which $i = 1, 2, \ldots, I$ items are to be purchased for $k = 1, 2, \ldots, K$ plants from $j = 1, 2, \ldots, J$ vendors, that provide different levels of item price, product quality, delivery performance, and product sustainability for items they sell. Also, depending on the buyer's total purchased value, vendor j offers a business volume discount having $r = 1, 2, \ldots, R_j$ discount brackets. The following lists the notation used to formulate the problem under consideration.

Problem Parameters

J_i = set of vendors offering item i,

I_j = set of items offered by vendor j,

K_j = set of plants that can be supplied by vendor j,

K_i = set of plants demanding item i,

D_{ik} = units of item i demanded by plant k,

c_{ijk} = unit price of item i quoted by vendor j for delivery to plant k,

q_{ij} = quality that vendor j maintains for item i which is measured as percent of defect,

t_{ijk} = delivery reliability that vendor j maintains for item i at plant k, measured as a percentage of units missing their scheduled delivery time window at plant,

g_{ij} = greenhouse gas emission (GHGE) of item i supplied by vendor j, measured by pounds of CO_2 imbedded in the item (lbco$_2$/unit),

S_{ij} = maximum quantity of item i that may be purchased from vendor j due to capacity constraints or other considerations,

u_{jr} = upper cutoff point of discount bracket r for vendor j,

l_{jr} = lower cutoff point of discount bracket r for vendor j,

d_{jr} = discount coefficient associated with bracket r of vendor j's cost function.

Decision Variables

x_{ijk} = units of item i to purchase from vendor j for delivery to plant k,

v_{jr} = volume of business awarded to vendor j in discount bracket r. Observe that $v_{jr} > 0$ only if the dollar amount of purchases made from vendor j falls within bracket r of its cost function; otherwise it is zero.

$$y_{jr} = \begin{cases} 1, \text{if the volume of business awarded to vendor } j \text{ falls on segment } r \text{ of its cost function;} \\ 0, \text{otherwise.} \end{cases}$$

Model Formulation

$$\min Z = [Z_1, Z_2, Z_3, Z_4] \tag{1}$$

$$Z_1 = \sum_{j \in J} \sum_{r \in R_j} (1 - d_{jr}) v_{jr} \tag{1a}$$

$$Z_2 = \sum_{i \in I} \sum_{j \in J_i} \sum_{k \in K_j} q_{ij} x_{ijk} \tag{1b}$$

$$Z_3 = \sum_{i \in I} \sum_{j \in J_i} \sum_{k \in K_j} t_{ijk} x_{ijk} \tag{1c}$$

$$Z_4 = \sum_{i \in I} \sum_{j \in J_i} \sum_{k \in K_j} g_{ij} x_{ijk} \tag{1d}$$

subject to:

$$\sum_{j \in J_i} x_{ijk} = D_{ik}, \qquad i \in I, \quad k \in K_i; \tag{2}$$

$$\sum_{k \in K} x_{ijk} \le S_{ij}, \qquad i \in I, \quad j \in J_i; \tag{3}$$

$$\sum_{i \in I_j} \sum_{k \in K_i} c_{ijk} x_{ijk} = \sum_{r \in R_j} v_{jr}, \qquad j \in J; \tag{4}$$

$$v_{jr} \le u_{jr} y_{jr}, \qquad j \in J, \quad r \in R_j; \tag{5}$$

$$v_{j,r+1} \ge l_{j,r+1} y_{j,r+1}, \qquad j \in J, \quad r = 1, \ldots, R_j - 1; \tag{6}$$

$$\sum_{r \in R_j} y_{jr} = 1, \qquad j \in J; \tag{7}$$

$$y_{jr} = \{0,1\}, \;\; v_{jr} \ge 0, \qquad j \in J, \quad r \in R_j; \tag{8}$$

$$x_{ijk} \ge 0, \qquad i \in I, \quad j \in J_i, \quad k \in K_j. \tag{9}$$

Constraint (2) represents the condition that the total demand of each item at each plant must be satisfied. Constraint (3) ensures that the quantity of items procured by each supplier to all plants is within the production and shipping capacity of that supplier. Constraint (4) determines the dollar amount of business awarded to vendor *j*. Constraints (5)-(6) link the purchase of the item with the business volume discount to the appropriate segment of the discount pricing schedule for each vendor. Constraint (7) ensures that only one discount bracket for each vendor's volume of business will apply. Constraints (8) and (9) ensure integrality and nonnegativity on the decision variables. Equation (1) specifies the multi-objective function whose components are given by equations (1*a*), (1*b*), (1*c*), and (1*d*). Equation (1*a*) minimizes the total purchase cost. Equation (1*b*) minimizes the quantity of defective items, Equation (1*c*) minimizes the number of items missing their scheduled delivery time window, and Equation (1*d*) minimizes the greenhouse gas emission of the total number of purchased items.

SOLUTION METHODOLOGY

Two basic approaches may be used to solve multiobjective programming problems. These are the preference-oriented approach and the generating approach. The preference-oriented approach consists of techniques that rely on a formal characterization of preferences among the objectives prior to solving the problem. Generating techniques are suitable to situations where the articulation of preferences among the objectives is postponed until a range of alternative *noninferior* solutions is examined (see Cohon, 1978, for a comprehensive discussion). These solutions help the decision maker to better understand the tradeoffs between the objectives before selecting a best-compromise solution. Tradeoffs between the objectives are however relatively difficult to understand when more than two objectives are at hand. For this reason, practitioners often prefer the preference-oriented approach to generating techniques. An application of the preference-oriented approach to our problem is discussed next.

Preference Oriented Approach

Assume that our procurement manager is in a position to articulate a value judgment between the objectives of high product quality, on-time delivery and greenhouse gas emission of sourced items in the form of some dollar value attached to such objectives. Let p_{ik} be the dollar penalty caused by one defective unit of item *i* at plant *k* to the purchasing organization. Also, let w_{ik} be the dollar penalty the organization suffers as a result of one unit of item *i* missing its scheduled delivery time window at plant *k*. Moreover, let h_i be the dollar opportunity cost suffered by the decision maker for each unit of greenhouse gas emitted by a purchased item. The Multi-objective function (1) can now be rewritten as:

$$\min Z = \sum_{j\in J}\sum_{r\in R_j}(1-d_{jr})v_{jr} + \sum_{i\in I}\sum_{j\in J_i}\sum_{k\in K_j} p_{ik}q_{ij}x_{ijk} + \sum_{i\in I}\sum_{j\in J_i}\sum_{k\in K_j} w_{ik}t_{ijk}x_{ijk} + \sum_{i\in I}\sum_{j\in J_i}\sum_{k\in K_j} h_i g_{ij}x_{ijk}$$

or

$$\min Z = \sum_{j\in J}\sum_{r\in R_j}(1-d_{jr})v_{jr} + \sum_{i\in I}\sum_{j\in J_i}\sum_{k\in K_j}(p_{ik}q_{ij} + w_{ik}t_{ijk} + h_i g_{ij})x_{ijk} \qquad (1')$$

Equation (1') is a single dimension (dollars) objective function, and our model can be now solved as a single-objective optimization problem. The optimal solution to Equation (1') subject to constraints (2)-(9) represents the *best-compromise solution* for the articulated values of p_{ik}, w_{ik}, and h_i.

CONCLUSION

This paper introduced a multi-objective mixed integer programming model to support purchasing decisions in sourcing environments where competing vendors with different product quality, on-time delivery performance, and carbon emission levels offer volume discounts based on the total value of multiproduct orders they receive from the buyer. The model can help an organization determine the optimal set of vendors to employ and allocates order quantities to these vendors, in such a way to concurrently minimize total purchase cost, maximize product quality, maximize on-time delivery reliability, and minimize carbon footprint of the purchased items.

Optimal solutions to procurement decisions are a valuable tool. They eliminate much of the subjectivity that impacts such decisions under highly competitive and complex sourcing environments. To this end the proposed model provides a comprehensive approach that can be used to support purchasing decisions in such environments.

References provided upon request.